Lightweight Nonmetallic Thermal Protection Materials Technology (LNTPMT) Project

ARC-JET Technology Workshop
Rice University, Houston, TX

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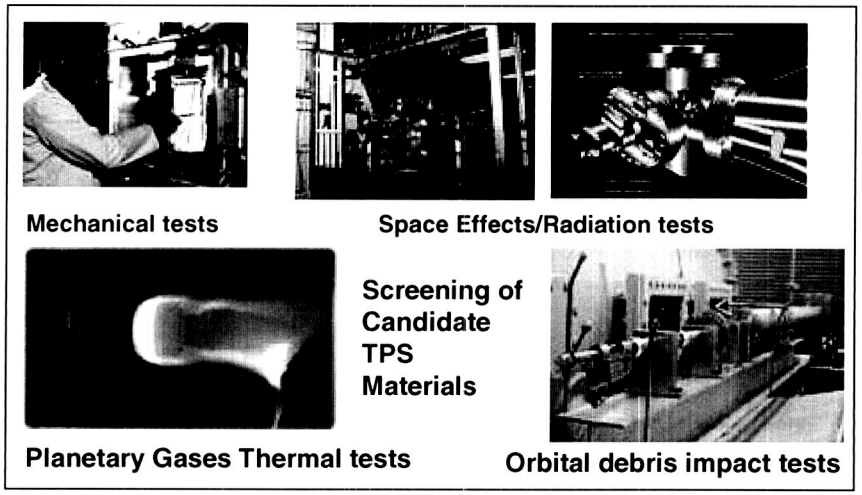

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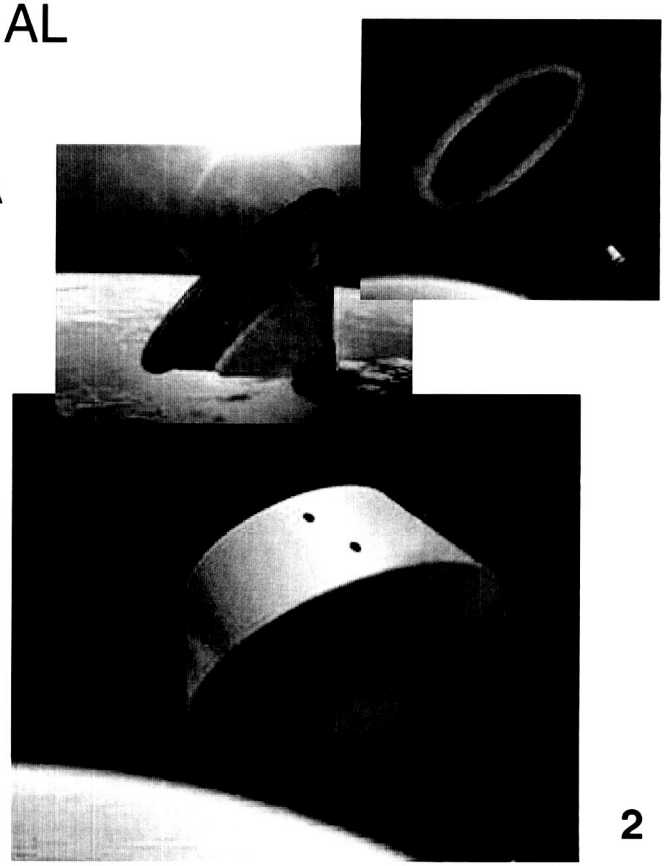
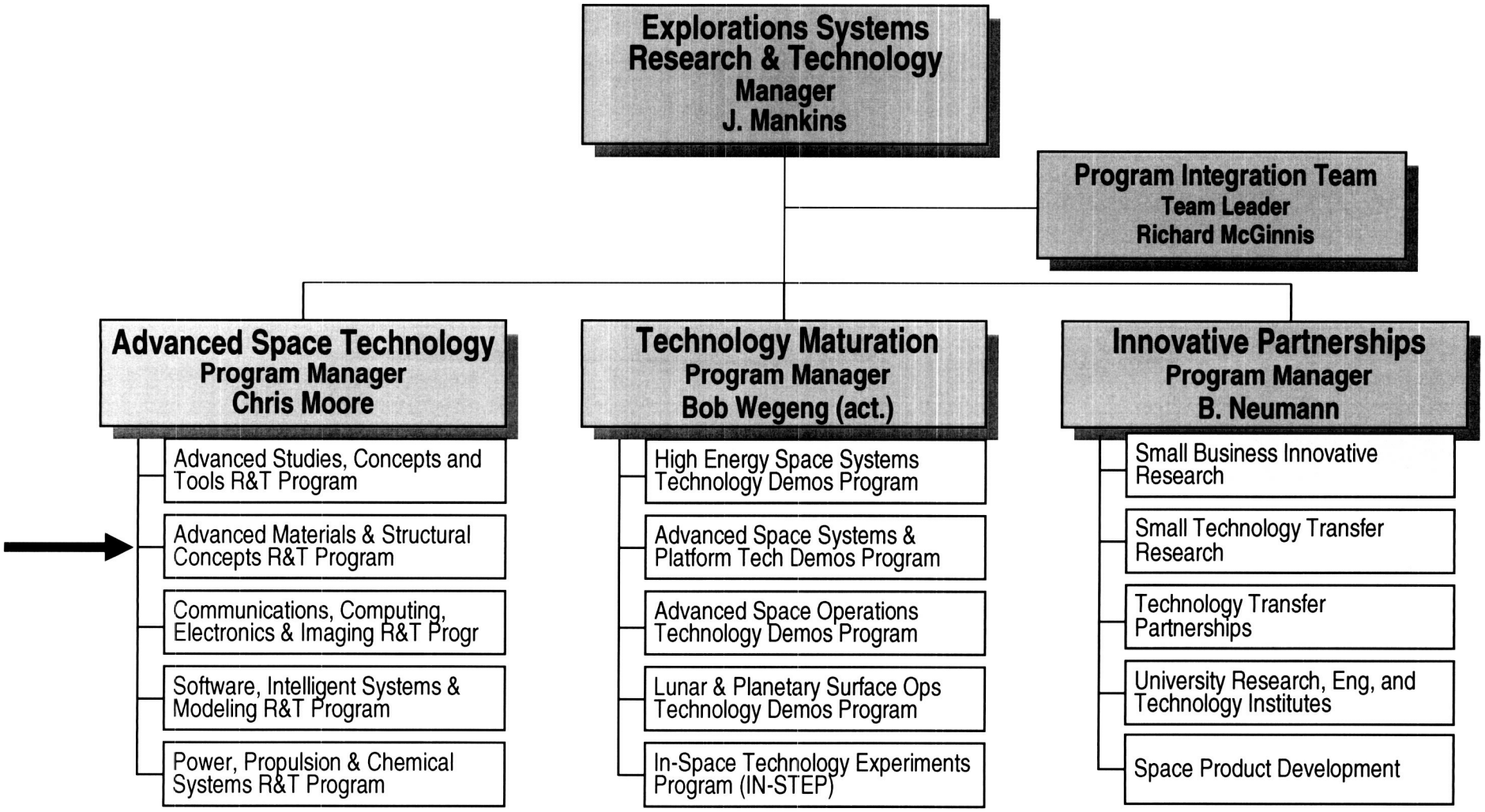


Overview Outline

- Exploration Systems Research & Technology Program Structure
- Project Objective
- Overview of Project
- Candidate Thermal Protection System (TPS) Materials
- Definition of Reference Missions & Space Environments
- Technical Performance Metrics (TPMs)
- Testing (types of tests)
- Conclusion

Exploration Systems Research and Technology (ESR&T) Structure



Organized by Discipline, Emphasizing the Longer-term

Organized by Functional-Area, Emphasizing Technology Validation

Organized by Program Function, Emphasizing Types of Relationships

Project Objective

- **To establish the TPS material technology roadmap, methodology, and screening testing process to mature lightweight nonmetallic TPS materials and demonstrate developed roadmap and methodology**
  - Screening tests will enable the development of a TPS database to enable comparison and assessment of candidate TPS materials by Exploration Systems vehicle designers
    - **Measurement of key TPS material properties**
    - **Assessments of material performance characteristics in relevant planetary gases (both simulated Earth and Mars atmospheres)**
    - **Assessments of material performance characteristics in pertinent space environmental conditions**
  - Project results will allow the early identification of areas that require more focused development efforts by the overall Exploration Systems team
  - Groundwork will be established for eventual qualification and certification of TPS and heatshield materials to be used on Exploration Systems vehicles

Overview of Project Tasks

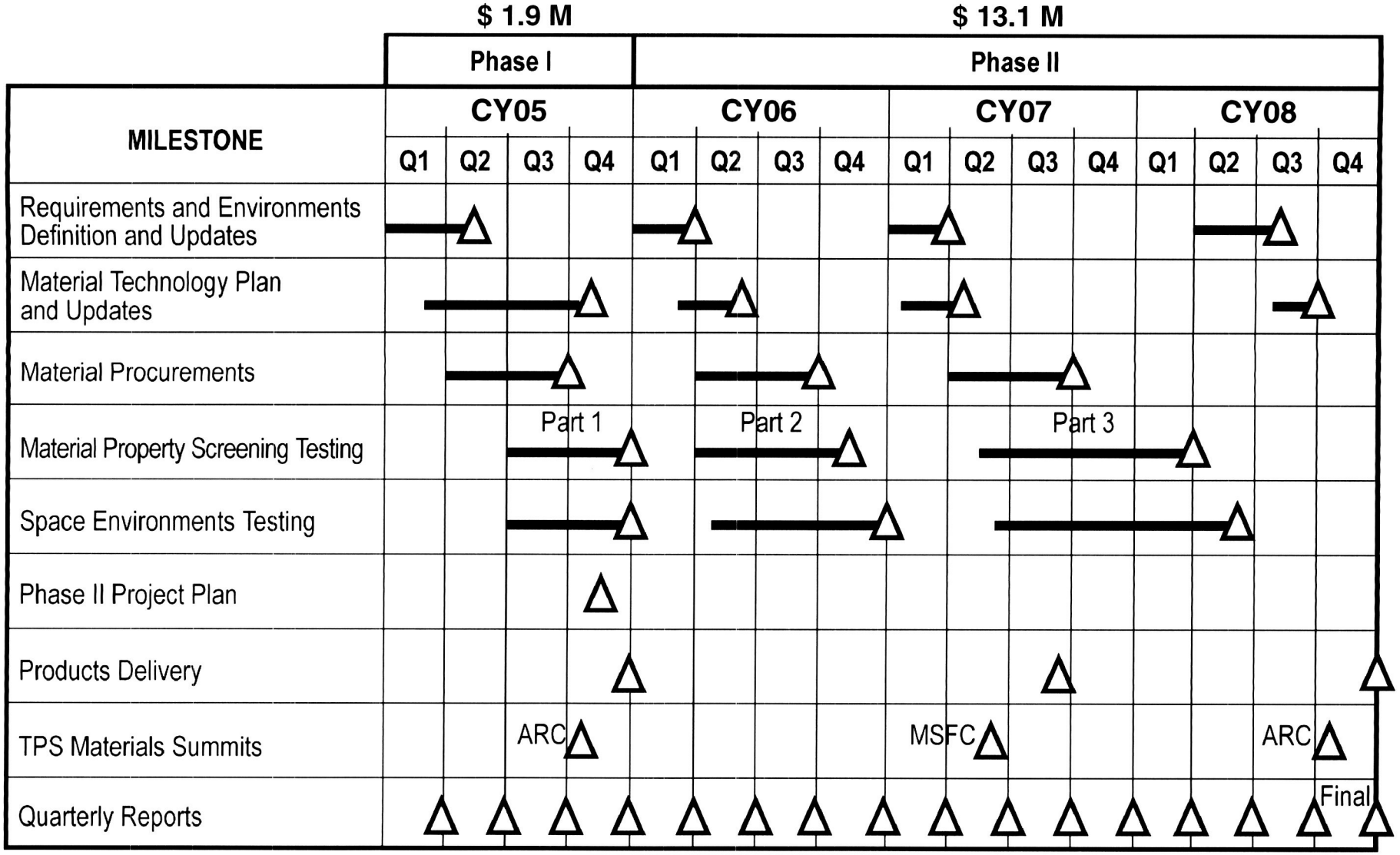
♦ Phase I tasks to be accomplished in 1 year effort:

- Definition of mission requirements, applicable environments, & technology advancement roadmaps
- Determination of specific material properties to be measured & specific environments to be evaluated
- Determination of materials to be considered & generation of test matrices
  - **Conducted Internal NASA Summit in March 2005 to facilitate this & previous 2 tasks**
  - **Request for Information (RFI) executed to facilitate industry input and/or involvement in the project**
- Testing of selected materials according to test matrices developed
  - **Material properties testing**
  - **Space environmental effects testing**
  - **Planetary gases testing in arc jet facilities**
  - **Combined effects & sequential effects testing**

♦ Phase II tasks to be accomplished in 3 year effort:

- Iterate process based upon close coordination with other Exploration Systems projects & industry (both aerospace & materials companies)
  - **Three TPS Materials Summits (one in Phase I --- Oct 05; two in Phase II)**

Overall Project Schedule



List of Candidate TPS Materials

Material Classes	Partial Listing of Candidate Materials Under Consideration	
Lightweight Ablatives	Lightweight Silicone Reinforced Ablators Low & Mid Density DoD Ablators	NASA Ames Silica Impregnated Ceramic Ablators NASA Ames Phenolic Impregnated Ceramic Ablators
Rigid Reusable Ceramics	Shuttle AETB Tiles NASA Ames High Emissivity Tiles	NASA Ames TUFROC Tiles
Ceramic Matrix Composites (CMC's)	DoD 2D/3D Carbon-Carbon DoD 2D/3D Carbon/Silicon-Carbide	2D CMC-Overwrapped Tiles
Ballute Thin Film Materials	In-Space Propulsion Ballutes NASA MSFC SBIR Ballutes	Aerogel Impregnated Films
Baseline/Reference Standard Materials	Mars Viking SLA-561 Ablator Shuttle Orbiter RCG Tile & RCC	Apollo Ablator Minuteman Ablator

NOTES:

- **The TPS materials to be investigated for Phase I are substantially complete or fixed.**
- **Materials to be investigated in Phase II are yet to be determined. Selection will be based upon the Phase I results, teaming arrangements, and the direction Exploration Systems takes.**

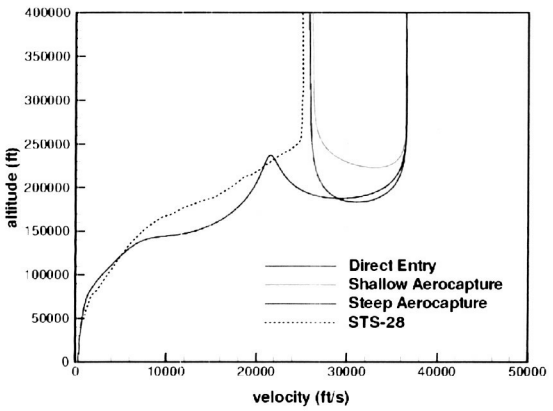
Missions & Environments

♦ Reference Mission Segments & Environments To Be Considered:

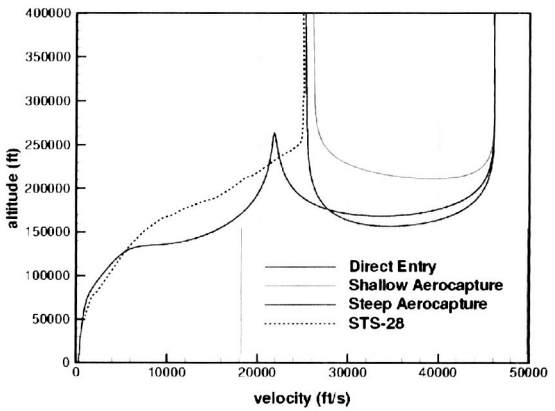
- Aeroentry, aerocapture, & aerobraking for both Earth & Mars
  - **Earth aeroentry/aerocapture upon returning from the Moon of greatest importance**
  - **Mars aeroentry/aerocapture upon arriving from the Earth**
- Long-duration deep space exposures
  - **Transit between Earth & Mars**
  - **Long duration Lunar orbit**
- Long duration low-Earth & low-Mars orbits

Definition & supporting analyses are on-going, for example:

Lunar Return Entry Trajectories

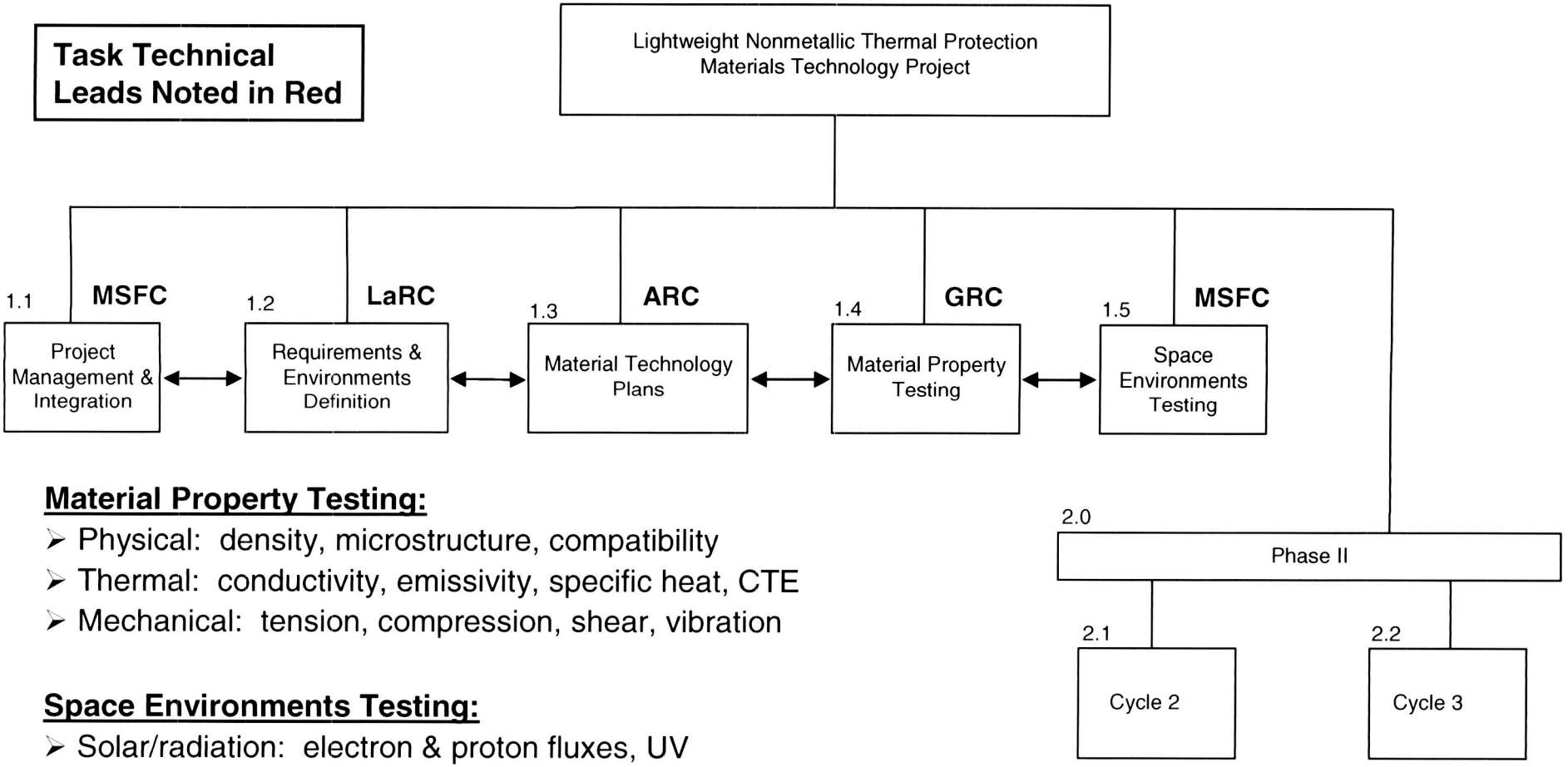


Mars Return Entry Trajectories



Testing Emphasized in 5-Task Effort

Task Technical Leads Noted in Red



Material Property Testing:

- Physical: density, microstructure, compatibility
- Thermal: conductivity, emissivity, specific heat, CTE
- Mechanical: tension, compression, shear, vibration

Space Environments Testing:

- Solar/radiation: electron & proton fluxes, UV
- Atomic Oxidation
- MMOD: hypervelocity impact
- Arc jet testing: Earth gases, Mars gases
- Multi-parameter: stressed oxidation
- Sequential or combined effects: SEE + arc-jet + residual mechanical properties

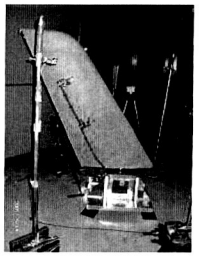
Technical Performance Metrics

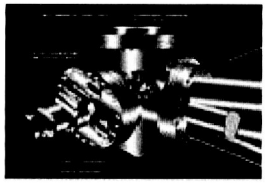
TPS Material Application/Reference Mission	Technology Metric	TPM Target	TPM Minimum Success Criteria
Direct Entry • Ablative	Heat rate	600 W/cm2	400 W/cm2
	Heat Load	50 KJ/cm2	30 KJ/cm2
	Density	<300 kg/cm3	<500 kg/cm3
	Loads	5 g's	20 g's
	MMOD	>1 cm	>1 mm
	Shock/Acoustic	20%> Apollo/Mars Viking	Apollo/Mars Viking
	Space Effects (maintain 80% thermal performance)	20%> Apollo/Mars Viking	Apollo/Mars Viking
Aerocapture • Non-ablative Ceramics/CMC's • Non-ablative Ceramics/CMC's w/ ballutes	Heat rate	>100 W/cm2 (>10 W/cm2)	>60 W/cm2 (>5 W/cm2)
	Heat Load	>40 KJ/cm2 (TBD)	>30 KJ/cm2 (TBD)
	Density *	<300 Kg/cm3, CMC<TBD Kg/cm3 (<TBD Kg/cm3)	<500 Kg/cm3, CMC<TBD Kg/cm3 (<TBD Kg/cm3)
	Loads	5 g's	20 g's
	MMOD	>1 cm	>1 mm
	Shock/Acoustic	20%> Apollo/Mars Viking	20%> Apollo/Mars Viking
	Space Effects (maintain 80% thermal performance)	20%> Apollo/Mars Viking	20%> Apollo/Mars Viking

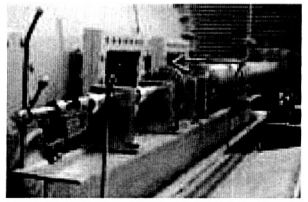
* Density/weight of CMC system TBD due to CMC performing as both TPS and primary structure.

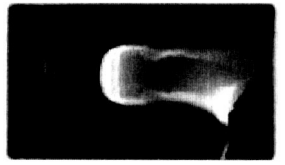
Planned Phase I Tests

Type of Test	Proposed Material	Center/Facility	Performance Measures
• Physical Property Tests (specific heat and density)	• Ablative	SRI	• Objective is 20%> Apollo/Mars Viking, Goal is 50%>, Minimum is equivalent, (i.e. <500 kg/cm3 density)
	• Non-ablative Ceramics	ARC	
	• CMC	GRC	
	• Ballutes/Inflatables	SRI	
• Thermal Property Tests (conductivity, emissivity, CTE.)	• Ablative	SRI	• Objective is 20%> Apollo/Mars Viking/Shuttle, Goal is 50%>, Minimum is equivalent
	• Non-ablative Ceramics	ARC	
	• CMC	GRC	
	• Ballutes/Inflatables	SRI	
• Mechanical Property Tests (tensile, shear)	• Ablative	SRI	• Objective is 20%> Apollo/Mars Viking/Shuttle, Goal is 50%>, Minimum is equivalent
	• Non-ablative Ceramics	ARC	
	• CMC	GRC	
	• Ballutes/Inflatables	SRI	
• Multiparameter Environments Tests (stressed oxidation)	• Ablative	LaRC	• Objective is 20%> Apollo/Mars Viking/Shuttle, Goal is 50%>, Minimum is equivalent
	• Non-ablative Ceramics		
	• CMC		
	• Ballutes/Inflatables		
• Acoustic/Vibration/Shock Testing Environments Tests	• Ablative	SRI	• Objective is 20%> Apollo/Mars Viking/Shuttle, Goal is 50%>, Minimum is equivalent
	• Non-ablative Ceramics	GRC	
	• CMC	GRC	
	• Ballutes/Inflatables	SRI	
• Solar Radiation Effects Environments Tests	• Ablative	MSFC	• Objective is 20%> Apollo/Mars Viking/Shuttle, Goal is 50%>, Minimum is equivalent, Long duration effects TBD
	• Non-ablative Ceramics		•
	• CMC		
	• Ballutes/Inflatables		
• Atomic Oxygen Effects Environments Tests	• Ablative	MSFC	• Objective is 20%> Apollo/Mars Viking/Shuttle, Goal is 50%>, Minimum is equivalent, Long duration effects TBD
	• Non-ablative Ceramics		
	• CMC		
	• Ballutes/Inflatables		
• MMOD Effects Environments Tests	• Ablative	MSFC/ARC	• Equivalent > Apollo/Mars Viking/Shuttle, MMOD >1cm (80% thermal performance), minimum >1mm
	• Non-ablative Ceramics		
	• CMC		
	• Ballutes/Inflatables		
• Planetary Gasses Heat Flux Effects Environments Test (plasma torch/arc jet, includes cycle testing after space effects)	• Ablative	MSFC/ARC	• >800 W/cm2, min >400 W/cm2
	• Non-ablative Ceramics		• >60 W/cm2, min >40 W/cm2
	• CMC		• >100 W/cm2, min >60 W/cm2
	• Ballutes/Inflatables		• >10 W/cm2, min >5 W/cm2









Space Environmental Effects

		Low Earth Orbit		GEO	Interplanetary
		Equatorial	Polar		
Vacuum	Solar UV	Independent of Orbit			
	Contamination	Independent of Orbit			
Neutral	Drag	Yes	Yes	N/A	N/A
	Sputtering	Yes	Yes	N/A	N/A
	AO Erosion	Yes	Yes	N/A	N/A
	Glow	Yes	Yes	N/A	N/A
Plasma	S/C Charging	Low	Mid	High	High
Radiation	Trapped Belts	Low	Mid	High	N/A
	Solar Particle Event	Low	Mid	High	High
	Galactic Cosmic Rays	Low	Mid	High	High
Micrometeoroid /Orbital Debris	Hypervelocity Impact	MM – Risk decreases with increasing altitude OD – Risk greatest in popular orbits			

- **Moon: -- No atmosphere, high radiation, temps from 400K to 40K, abrasive dust, 1/6 g**
- **Mars: -- CO_2 atmosphere (1% of Earth's density), 38% g, dust, winds, 40% Sun's radiation**

Benefits/Payoff

- Advance the Technology Readiness Levels (TRL's) of promising Exploration Systems TPS material candidates
- Synergistic with DoD (AMRDEC, MDA, Falcon) and DoE (Sandia) efforts --- sharing of test materials, test data, costs
- Creation of roadmaps and plans for developing Exploration heatshield TPS materials
- Fill in gaps in existing TPS material databases
- Assess the performance of TPS material candidates when exposed to the following:
  - Space Environmental Effects (SEE)
  - Simulated re-entry conditions (arc jet testing in Air & CO_2)
  - Combined effects testing

Risks/Other Options

- The primary risks of not conducting this project are that:
  - Viable TPS options will not be available to Exploration Systems vehicle developers in the timeframe required
  - Gaps in TPS material databases will preclude the consideration of specific materials
- This project offers the Exploration Systems organization and the CEV developers an established team and on-going project that can rapidly be expanded and/or accelerated to meet new NASA goals and accelerated vehicle development schedules

Team Members

- **Primary Organizations Involved In Project:**
  - NASA Marshall Space Flight Center (MSFC)
    - Non-Metals Engineering Branch (EM40)
    - Environmental Effects Branch (EM50)
    - Space Transportation Programs & Projects Office (NP)
    - Engineering Directorate Test Laboratory (ET21 Branch)
    - Natural Environments Branch (EV13)
  - NASA Ames Research Center (ARC)
  - NASA Glenn Research Center (GRC)
  - NASA Langley Research Center (LaRC)
  - Southern Research Institute (SRI)
- **Supporting Organizations & Consultants:**
  - NASA Johnson Space Center (JSC)
  - Air Force Research Laboratory (AFRL) @ WPAFB
  - Sandia National Labs
  - Naval Surface Warfare Center (NSWC)
  - Redstone Arsenal's AMRDEC (Aviation & Missile Research, Development, & Engineering Center)
- **Industry (Aerospace, Materials, Etc.): TBD**